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THE CORRELATION AND RECONSTRUCTION OF RECESSIONAL ICE BORDERS IN BERKSHIRE COUNTY, MASSACHUSETTS.[1]

PRELIMINARY STATEMENT.

THE studies which form the basis of this paper were made chiefly in connection with the mapping of the surficial geology of the Housatonic quadrangle, which comprises the southern two-thirds of Berkshire county and lies mainly in western Massachusetts, but partly also in New York and Connecticut. The southern half of the Taconic quadrangle, comprising the northern third of Berkshire county and an equal area in New York, is also included. This presentation of some of the results is offered by permission of Professor T. C. Chamberlin, under whose direction the studies were made.

One of the most important things brought out by the study of this area relates to the retreat of the ice-sheet, or, rather, to the retreat of its frontal edge or margin, across Berkshire county. As is well known from the extensive studies of Chamberlin,[2] Leverett,[3] and others in the states west of New York, the retreat

[1] An abstract of this paper was presented before Section E of the A. A. A. S. at Washington, January 2, 1903.

[2] T. C. CHAMBERLIN, "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch," *Third Ann. Rep. U. S. Geol. Surv.*, 1883.

[3] FRANK LEVERETT, "The Illinois Glacial Lobe," Monograph XXXVIII, *U. S. Geol. Surv.*, 1899.

of the ice-front in that region was not by an even, steady movement giving a uniform rate of recession, but by oscillations in which there were many alternating episodes of relatively rapid retreat and less marked readvance separated by times of halting, when the ice-front remained for some time in a stationary state. These minor oscillations with repeated haltings characterized the whole of the main movement of retreat of the last ice-sheet in the West. Each halt was the occasion of the building of a frontal or marginal moraine, and the drift of the Wisconsin epoch is nearly everywhere marked by a numerous series of these *recessional* moraines.

HISTORICAL.

In the East the ice-sheet was long thought to have had a different habit, and to have made no recessional moraines like those of the West. The two great marginal moraines extending westward along the coast from Cape Cod and Nantucket Island, and converging toward the west end of Long Island, have been known for many years.[1] The extension of one of these as the so-called "terminal moraine" of H. Carvill Lewis, having a general course west-northwest across New Jersey and Pennsylvania, is also well known.[2] These, however, are not recessional moraines, but the frontal deposits of the grand climax, when the ice-front rested after the general advance and before the general retreat.

Leverett has mapped the recessional moraines of the extreme western portion of New York and of the northwestern part of Pennsylvania, and he has also mapped in detail the morainic deposits of the Olean and Salamanca quadrangles in western New York. The folios to which these belong have not yet been published, but a map of the Olean quadrangle has been issued

[1] WARREN UPHAM, "Terminal Moraines of the North American Ice Sheet," *Am. Jour. Sci.*, III, Vol. XVIII (1879), pp. 81–92, 197–209.

[2] GEORGE H. COOK, "On the Southern Limit of the Last Glacial Drift Across New Jersey and the Adjacent Parts of New York and Pennsylvania," *Am. Inst. Min. Eng. Trans.*, Vol. VI (1879), pp. 467–520; H. CARVILL LEWIS, "Report on Terminal Moraine Across Pennsylvania and Western New York," *Second Geol. Surv. of Penn.*, *Rept. Z.*, 1884.

as a pocket map with Leverett's second monograph.[1] With these exceptions, the recessional moraines of Pennsylvania and New York have been recognized in only a few places and in short and scattered fragments. Salisbury has mapped a few fragments of recessional moraines which cross northern New Jersey.[2]

Essentially the same statement applies to New England. Emerson has identified a number of positions of the ice-front in central Massachusetts in places where it served as the retaining barrier for temporary glacial lakes or for the building of terraces of sand and gravel.[3] Woodworth has mapped two recessional halts on the western end of Long Island back of the great terminal moraine, and has made out the position of several consecutive ice-fronts by sand plains in the vicinity of Narragansett Bay.[4] Grabau has done the same in southeastern Massachusetts in the study of Lake Bouvé.[5] Crosby has found one or two morainic fragments and the positions of several ice barriers for lakes in northeastern Massachusetts.[6]

While these observations have added much to our knowledge, no considerable consecutive series of halts has been made out through them, nor has the course of the ice-front at any particular halt been traced continuously across the country for scores

[1] FRANK LEVERETT, "Glacial Formations and Drainage Features of the Erie and Ohio Basins," Monograph XLI, *U. S. Geol. Surv.*, 1902.

[2] R. D. SALISBURY, "Glacial Geology," *Geol. Surv. of New Jersey*, Vol. V (1902); also, "Pleistocene Formations," *New York City Folio, U. S. Geol. Surv.*, Folio No. 83, 1902.

[3] B. K. EMERSON, "Pleistocene," *Holyoke Folio, U. S. Geol. Surv.*, Folio No. 50, 1898; also, "Geology of Old Hampshire County, Massachusetts," Monograph XXIX, *U. S. Geol. Surv.*, 1900; also, "Geology of Eastern Berkshire County, Massachusetts," *U. S. Geol. Surv.*, Bull. No. 159, 1899.

[4] J. B. WOODWORTH, "The Retreat of the Ice Sheet in the Narragansett Bay Region," *Am. Geol.*, Vol. XVIII (1896), pp. 150–68; also, "Pleistocene Geology of Portions of Nassau of Queens County and Borough," *N. Y. State Mus. Bull.* No. 48, 1901.

[5] A. W. GRABAU, "Lake Bouvé, an Extinct Glacial Lake in the Southern Part of the Boston Basin," *Boston Soc. Nat. Hist., Occ. Papers*, Vol. IV, Part 3 (1900), pp. 601–94.

[6] W. O. CROSBY, "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods," *Tech. Quart.*, Vol. XII (1899), pp. 288–324.

of miles, as is common in the West. Indeed, few if any have been traced as far as ten miles. Nor has any method of correlating the moraine fragments been worked out by which the individual ice borders may be plausibly reconstructed across the rugged country of New England. Because a distinct series of recessional moraines has not thus far been found in the East, the impression has prevailed in some minds that the ice-sheet may not have had the oscillations and halts that it did in the West. But this opinion has been held in spite of the suggestive significance of the fragmentary evidences just mentioned. The recent studies in Berkshire county have disclosed the fact that, at least within its boundaries, and in much of the country contiguous to it, the recessional halts did take place with usual regularity, and that fragmentary moraines were built along the several lines on which the ice-front rested. It is more the object of the present paper to show in particular what results bearing on the manner of the retreat of the ice-front have been attained by these studies.

TOPOGRAPHY.

The topography of Berkshire county is a rugged and varied one. The development of the present relief and its drainage systems has been almost entirely the work of subaërial agencies. Rain and frost and streams like those now there have done the work. Glacial erosion has been very slight. The development of the relief has followed the distribution of the harder and softer rocks, and lines of weakness in the former. The harder members are the mountains and uplands of today, while the valleys follow mainly the lines of the softer strata. The quartzite and gneiss of the Green mountain range, the various gneisses of Hoosic mountain and the plateau to the south, the Berkshire and Greylock schists of Greylock mountain, and the Berkshire schist of Mount Washington and the Taconic range constitute the principal areas of the harder rocks, and they are all areas of high relief, while the Stockbridge limestone and a few other less extensive, but relatively soft, strata lie chiefly in the valleys, and have determined their place and extent.

Although the Berkshires are a mountainous region the

mountains are relatively small and low. The extremes of relief range from about 565 feet above sea level on the Hoosic river north of Williamstown, and about 650 feet on the Housatonic river below Ashley Falls, to 3,505 feet on Greylock mountain and 2,624 feet on Mount Everett, otherwise known as the Dome of Mount Washington. The two principal rivers are the Housatonic, flowing south, and the Hoosic, flowing north and northwest. Their valleys are the principal valleys of the county and are united as one trough across a col about three miles northeast of Pittsfield. The altitude of this col is about 1,120 feet above tide. Some of the main sources of the Hoosic are near the col, but the Housatonic, coming from the east, receives branches of some size from the north and west near Pittsfield. The extensive area of Stockbridge limestone stretching south from the vicinity of Pontoosuc lake three miles north of Pittsfield gives rise to the broadest valley of the county. Its usual breadth is from four to six or seven miles, but for twenty miles south-southwest of Pittsfield it is broken by isolated faulted mountains, and between these from Glendale to Housatonic the river flows through a narrow gorge-like valley.

Mount Washington, which is the highest point of the southern Berkshires, rises in considerable part above 2,000 feet. Excepting this, the higher lands in the southern and southeastern Berkshires commonly reach an altitude but little above 1,600 to 1,800 feet. The plateau of the southeastern part, however, is trenched by the deep, narrow valleys of the Westfield and Farmington rivers and their branches.

In the northern third of the county the reliefs become greater. Excepting in the vicinity of Williamstown, the Hoosic valley is seldom more than a mile wide in its lower levels. South of Williamstown a considerable area of limestone develops a broader lowland along Green river, and where this merges with the Hoosic valley it has the effect of broadening the latter.

The mountain masses bounding the Hoosic valley are considerably higher than those to the south. A large part of the Greylock mass rises above 2,000 feet, as does also the main crest of Hoosac mountain, East mountain, the Taconic range, and the

southern end of the Green mountain range. In these ranges heights of 2,400 to 2,600 feet are quite common.

GENERAL ICE MOVEMENTS.

From their studies of striæ and bowlder transportation the earlier geologists, E. Hitchcock,[1] L. Agassiz,[2] and others, found that the ice-sheet moved across Berkshire county in a southeasterly direction, along the Hudson river in a southerly direction, and on the slope west of the river in a southwesterly direction, showing thus a wide southward spreading of the ice from the axis of the Hudson valley. This spreading of striæ characterizes the valley through its whole length from south to north. Such an arrangement of striæ shows that the valley was occupied at all stages of retreat by a great glacier lobe which projected far south from the general line of the ice-front and spread away laterally over the country both to the east and west of the river. Berkshire county was therefore overrun by ice from the Hudson valley lobe and may be said to lie within the territory of its retreating eastern limb. The recent studies fully confirm this conclusion from other evidences also, such as the alinement of drumlin axes, the position of stoss-side smoothing of the hills, and still more and with independent conclusiveness from recessional moraines and border drainage. It is found that in retreating from southeast to northwest diagonally across the county the ice-front halted fourteen times; that is to say, the east limb of the Hudson lobe oscillated or wavered that many times in retreating about fifty miles.

[1] E. HITCHCOCK, "On a Singular Case of the Dispersion of Blocks of Stone at the Drift Period in Berkshire County, Massachusetts," *Am. Jour. Sci.*, Vol. XLVII (1844); and Vol. XLIX (1845); also, "Illustrations of Surface Geology," *Smithsonian Contrib.*, Vol. IX (1857, and second edition, Amherst, 1860.) C. H. HITCHCOCK, "On the Marks of Ancient Glaciers on the Green Mountain Range in Massachusetts and Vermont," *A. A. A. S., Proc.*, Vol. XIII (1860), pp. 329–35.

[2] L. AGASSIZ, "Glacial Scratches in Berkshire and Wachusett Ranges, Massachusetts," and "Observations on a Set of Bowlders in Berkshire County, Massachusetts," *Boston Soc. Nat. Hist. Proc.* Vol. XIV (1872). Other early papers on the Richmond bowlder trains are by H. D. and W. B. ROGERS, *Boston Soc. Nat. Hist.*, Vol. V (1847), pp. 310–30, and by E. DESOR, *ibid.*, Vol. II (1848). But the most exhaustive paper is by E. R. BENTON, *Harvard Mus. Comp. Zool. Bull.*, Vol. V (1878).

GENERAL RELATIONS OF THE RETREATING ICE-FRONT TO THE LARGER LAND RELIEFS.

It is interesting to note the general relations of the larger features of the land relief to the receding ice-front; for, according as the ice-front retreated across them in one direction or another, the recessional history of the region was one thing or another very different thing. The earlier investigators found that the general direction of ice-movement was about S. 30° to 40° E. It is a general principle that the direction of ice-movement at any point near the ice-front is about normal to the margin, so that in this case the general trend of the ice-border was presumably northeast and southwest, and remained so during its retreat across the county.

The southeastern part of the county is occupied by the high plateau already referred to. While the ice-front was retreating across this area, the Westfield and Farmington rivers drained the waters freely away from the ice-front. But when the retreat had reached the western edge of the plateau, the ice-sheet obstructed the drainage of several relatively small valleys and caused the formation of temporary lakes. When it rested in the Housatonic valley, the ice-front had free drainage to the south in every position but one. From the bend south of East Lee to that west of Glendale the river flows west. During one of its halts the ice obstructed the passage at Glendale, so that the valley to the east was occupied by a lake of considerable size. West of the Taconic range in Canaan and New Lebanon in New York, more lakes were produced at a later stage in the westwardly draining valleys of that region.

But the largest lake in the Berkshires was that which was held in the Hoosic valley. The Hoosic river flows north as far as North Adams, and thence west and northwest. Throughout its whole course in Massachusetts and Vermont, and for some distance in New York, the retreating ice-sheet obstructed the normal direction of flow. The consequence was that this valley with its principal branches — the valleys of Green river and the Little Hoosic — was filled first with independent lakes, which later merged into one long, irregularly shaped body that

filled the whole valley up to the contour of about 1,110 or 1,120 feet, according as one or another of two outlets was active. Geographical considerations, which ought to control wherever possible, would suggest Lake Hoosic as the most appropriate name for this body of water. Professor T. Nelson Dale, who has described certain features which he attributes to this lake, has called it Lake Bascom in published notices. But I shall use the geographical name as being decidedly better. One of the effects of Lake Hoosic was to obliterate and render unrecognizable the deposits of the ice-front where its halts rested in the northern, deeper part. This greatly increased the difficulty of distinguishing the successive halts in that part of the area.

If the ice-front had retreated from northwest to southeast, instead of in the opposite direction, the Hoosic would have been the valley of free drainage with valley trains of gravel, and the Housatonic, Westfield, and Farmington valleys would have had the lakes with deltas. The fact that, excepting in one small part where there are deltas, the Housatonic has only valley trains, and that the Westfield and Farmington have the same, while the Hoosic valley has deltas and lake clays, but no valley trains, accords well with the evidence of striæ and bowlder transportation, showing that the ice-front did in fact retreat in a general direction from southeast to northwest.

EVIDENCES BY WHICH THE RECESSIONAL HALTING PLACES OF THE ICE-FRONT WERE DETERMINED.

While the general retreat was going on across this region, the ice-front halted many times and formed a series of recessional moraines corresponding in a general way with the recessional moraines of the Great-Lake lobes in the West, except that they are very fragmentary and relatively faint and slender. The successive individuals are also on the average more closely spaced, the average interval between the halts in Berkshire county being about three and one-half miles, and they are all intensely sinuous in their courses.

There are, however, other classes of deposits which assist very materially in determining the place of the ice-border.

Besides (1) the moraines just mentioned, which are purely ice-laid sediments, there are (2) kames, eskers, and the like, which were made by the joint action of the ice and running water, and which may generally be relied upon as good supplementary evidence; and (3) eroded river channels along the border of the ice, outwash gravel fans, valley gravel trains, deltas, etc.

Excepting for the small isolated kames which occur in sporadic fashion, kames, and especially kame clusters, are essentially ice-border phenomena and are substantially equivalent to marginal morainic deposits. They nearly always occur at or very near the margin of the ice and are very commonly associated with moraines.

Eskers are not quite so closely related to the ice-front, and yet they are generally valuable aids; for, although they may extend for miles back, they nearly always take on a characteristic modification of development where they emerge from the ice. At such places they often take the form of a small kame cluster or delta, or sometimes an outwash fan. When an esker persists during several recessional halts, it generally shows one or another of these modifications at each place where the ice-front halted, although its ridge may be typically developed in the intervals. A good example of this sort may be seen in the great esker which runs south from North Adams to Berkshire.

Deposits of the third class often show the place of the ice-front in situations where there are no contiguous recognizable morainic deposits. In the Berkshires especially this class of evidence has been invaluable. Eroded river beds along the border of the ice are traceable for long distances only where the ice-front rested against a long unbroken mountain flank, as of the Green mountain range or of Hoosac mountain. But there are many places where shorter fragments of river beds are well developed. The streams that made them were not large, as a rule, but they are often very clearly cut in situations where their occurrence would be altogether impossible without the immediate presence of the ice-front to serve as one of the retaining banks. These fragments often occur on hillsides and steep valley slopes, and in other situations where the morainic deposits are absent or

are so lacking in the usual characters of moraines as to be not surely recognized when taken by themselves. The occurrence of an old river bed at the upper limit of a hillside belt of bowldery till which has no particular morainic expression makes a combination as surely indicative of the presence of the ice-border as if it were a well-developed moraine. One of the most remarkable river beds of this kind runs along the flank of Dry hill between Hartsville and New Marlboro.

Outwash gravel fans also occur occasionally in such a way as to mark the place of the ice-front where no certain morainic deposits are discoverable. A small deposit of this kind in front of a faint moraine occurs near the base of Mount Washington west of Sheffield.

There are several moraine-headed gravel trains in the Housatonic and other freely drained valleys. These show the halting places of the ice-front quite clearly and may be safely relied upon. The gravel trains which head at Housatonic and at State Line and at Pittsfield are good examples.

Deltas occurring in association with moraines, and sometimes also with kames, are also valuable adjuncts to interpretation. The magnificent terrace at Lenoxdale combines moraine and kame with delta.

SOME DESCRIPTIVE DETAILS OF MORAINES AND BORDER DRAINAGE.

A brief description of a few of the better examples of moraines and border drainage will now be given. The morainic deposits associated with the ice-front may be divided into three or possibly into four classes:

1. *Frontal or marginal moraines, resembling those of the Great-Lake lobes in the West.*—These are ridges of bowldery till in which clay is a relatively large constituent. They have usually a swell-and-sag topography, but also more or less knob-and-basin development. In the West this type of moraine is most characteristically developed on a plain country along the straight or gently curving margin of a great lobe. There is but one typical and strongly developed example of this class in Berkshire county. This fragment runs three miles southeast from Pittsfield.

It is about a mile broad, has a beautifully undulating surface, the higher swells reaching an altitude of sixty feet above the surrounding plain. Clay is a large factor in its composition, and it originally carried a great number of bowlders on its surface. It is built out across an open part of the Housatonic valley and was made by an ice-tongue which came from the north out of the Hoosic valley. The fact that this tongue deployed upon an open plain caused it to expand as it advanced, and no doubt gave its moraine the character described rather than that of the next class of deposits, which is much more common in the Berkshires. There are moraines of this type, but not so well formed, west of Hoosick Falls, N. Y., and there is a small fragment of similar character three-fourths of a mile north of Ashley Falls.

2. *Terminal moraines of ice-tongues.*—This class of moraines is the best developed and the most common type in the Berkshires, but it has both advantages and disadvantages as a means of tracing the ice-borders. It is always fragmentary and limited in extent, being confined in its best developments to the terminal parts of sharply pointed tongues in relatively deep and narrow valleys. On the other hand, excepting the first class, it is the most easily and most certainly recognizable form of moraine. These deposits are as a rule much coarser in composition than either of the other three classes. Clay is usually a relatively small constituent, and knob-and-basin topography is the common form of expression. In many respects they resemble kames in the forms they take, and many of them might well be mistaken for such if their composition and the circumstances of their occurrence were left out of account. They nearly always contain a large percentage of gravel, and in this, too, they remotely resemble kames. But as a rule they contain some clay and a very large proportion of the coarser sediments, sometimes being composed mainly of cobbles and bowlders, with only a filling of gravel and sandy clay. Not infrequently small bodies of stratified sand and gravel occur in them. They may be distinguished from kames, however, by the fact that their best development occurs in narrow valleys where there was free drainage from the ice, while typical kames occur where there was more or less local

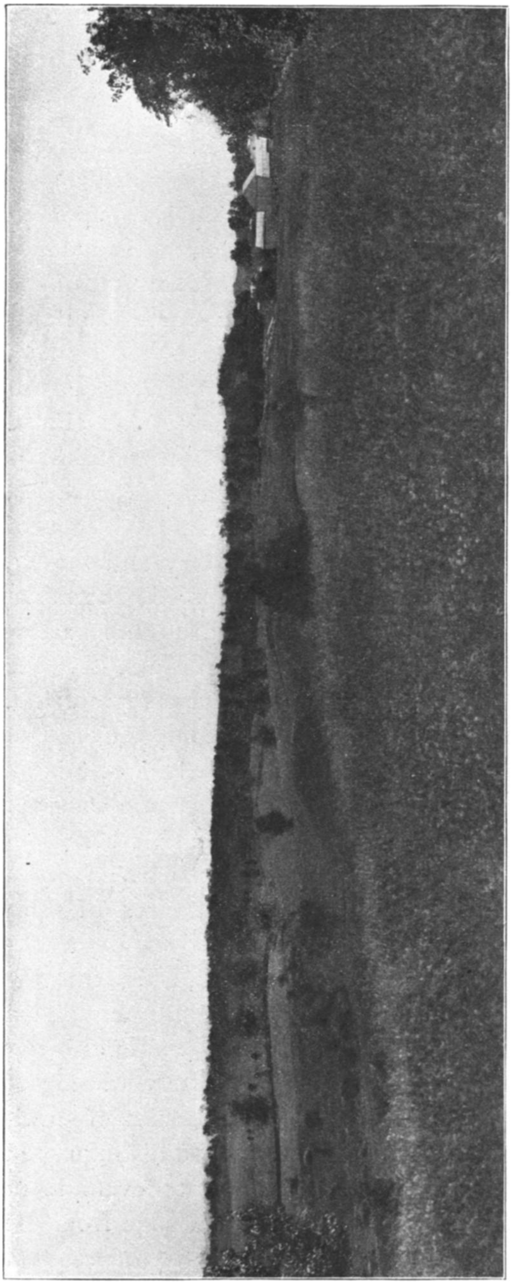

FIG. 1.—Looking southeast, one mile south of Cummington, Mass. Knolls of terminal moraine in middle ground.

ponding of the water. They are generally much coarser in composition than typical kames, and as a rule their knobs are lower and their basins shallower.

One of the best terminal moraines found is on the east side of the Farmington river, one mile north of Riverton, Conn. Besides the usual topography and coarse composition of terminal deposits, this one is thickly covered with huge blocks. Another, nearly as fine, was made at the next halt and is partly deposited on a low rock terrace below Hanging mountain, two miles south of New Boston, Mass.

Fig. 1 shows a well-developed terminal moraine one mile south of Cummington,

Mass. Its topography is shown in the middle ground and is very characteristic, the wave-like knolls ranging from ten to fifteen feet in height, with sags and occasional shallow basins between. A broken esker leads to this moraine from the direction of Cummington. The deposit is about a mile wide from north to south. On its outer southward slope there are a few knolls of coarser composition and a small gravel train heads at the moraine. This moraine appears to have blocked the original valley of Westfield river, which formerly went directly south from Cummington, but now goes around to the east through a narrower valley past Swift River.

Fig. 2 is two miles north of Stamford, Vt., and shows a remarkably fine specimen of the deposits of an ice-tongue. The rounded knolls to the right and left below the higher hills are mainly morainic, and are twenty to thirty-five feet or more

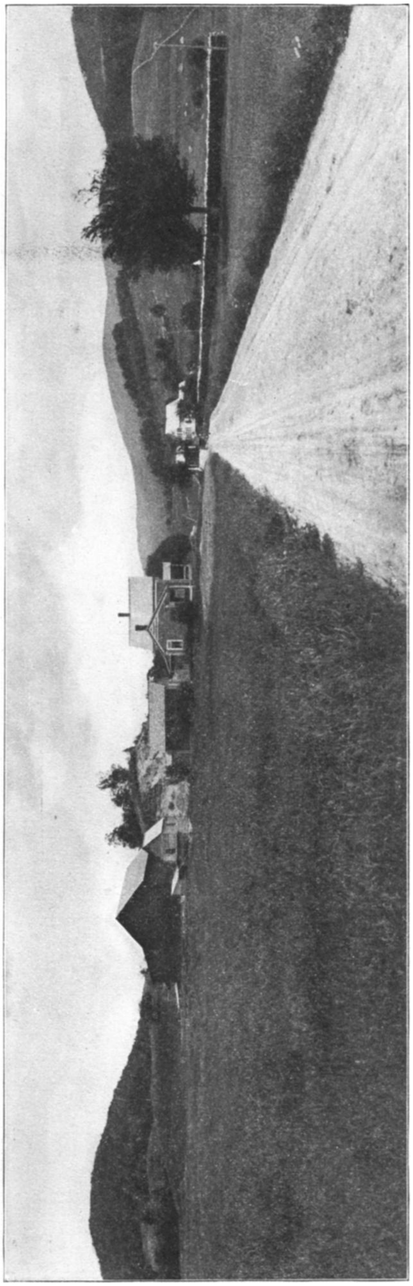

FIG. 2.—Looking north, two miles north of Stamford, Vt. Morainic knolls on right and left; end of esker between house and barn.

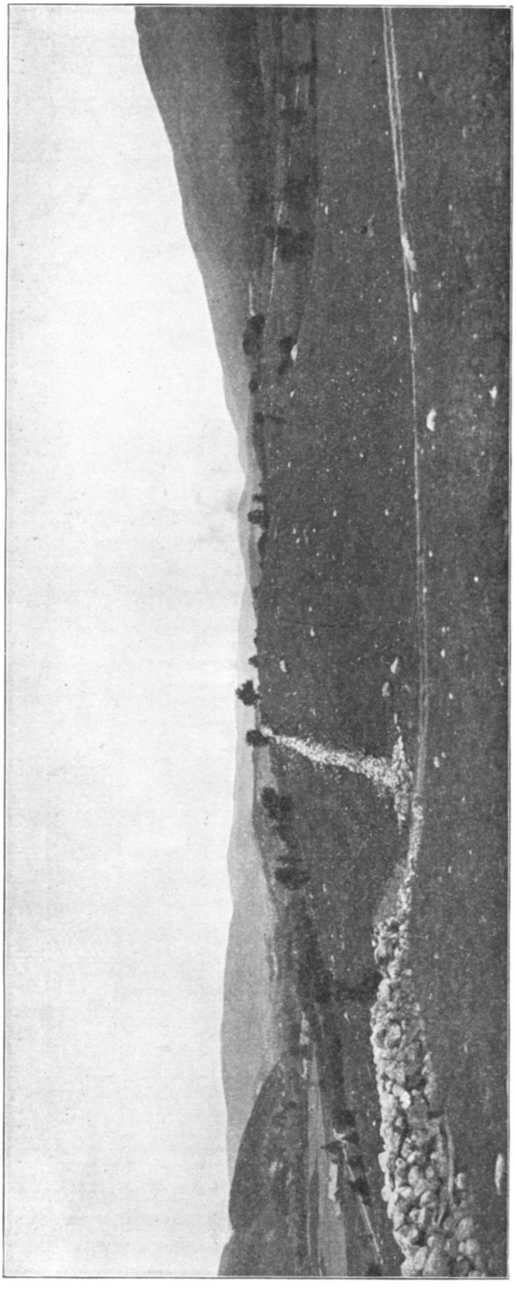

FIG. 3.—Looking north, two miles south of North Adams, Mass.

in height. The knoll seen between the house and barn is the outer end of an esker and is composed of fine stratified sand. This ice-tongue came from the north and ended in a lake in water probably fifty to one hundred feet deep. The deposits of this moraine are strongly developed for nearly two miles farther north.

Fig. 3 is south of North Adams. The stony knolls in the immediate foreground are part of a fringe of morainic knolls deposited on the outer edge of the great terrace along the base of Hoosac mountain. These knolls partake somewhat of the character of kames in their composition, but are nevertheless ice-border

deposits. The body of the great terrace upon which this moraine rests is composed of limestone.

3. *Lateral moraines of ice-tongues.*—This class is probably much more extensive, measured along the sinuous length of ice-borders, than all the others put together. But, with a few marked exceptions, it is extremely difficult to recognize with certainty. It is also extremely whimsical in its occurrence. In many situations where one would expect to find it there is no sign of it, while in other places it may be splendidly developed where one would not expect it.

The principal difficulty in recognizing this type of moraine with certainty is its lack of distinctive characters. The place and manner of its occurrence and its association with other border features are the principal guides to its recognition. As would be expected, lateral moraines generally occur on hillsides or the sides of valleys, and often where they are steep. In surface expression and in composition they appear to differ in no important respect from the relatively smooth and featureless stony till of the ground moraine. Sometimes low knolls of coarser composition, and frequently small kames with more or less gravel and sand, are associated with their upper edges, but seldom enter into their composition as an important quantity. Sometimes the mass of drift composing them forms a thick bank —ten or twenty feet, or even more—and their recognition is easy. But oftener it is thin, and their recognition is then difficult or impossible. They are most easily recognized when associated with strong border drainage. Where such a moraine is banked up on a valley side and a river of some volume flowed along the side of the tongue, the bed of the stream puts a very sharp upper limit to the heavier belt of drift, which is then readily recognized as a *submarginal* deposit of the ice. Usually, too, the hillside above the river bed is bare or only thinly coated with drift. Occasionally these moraines are distinct where border drainage was absent or too slight for recognition, their upper limit being determined as before by a line dividing a heavy bank of drift below from a thinly coated surface above. Where border drainage was very strong, a ridge of coarse detritus was

sometimes built along the edge of the ice and left there upon its retreat as a distinct narrow ridge forming the outer bank of the river bed. A beautiful example of this kind occurs on the west slope of Dry hill between Hartsville and New Marlboro. There are three of these river beds at this locality, with vertical intervals of fifteen or twenty feet. The lower one is the most

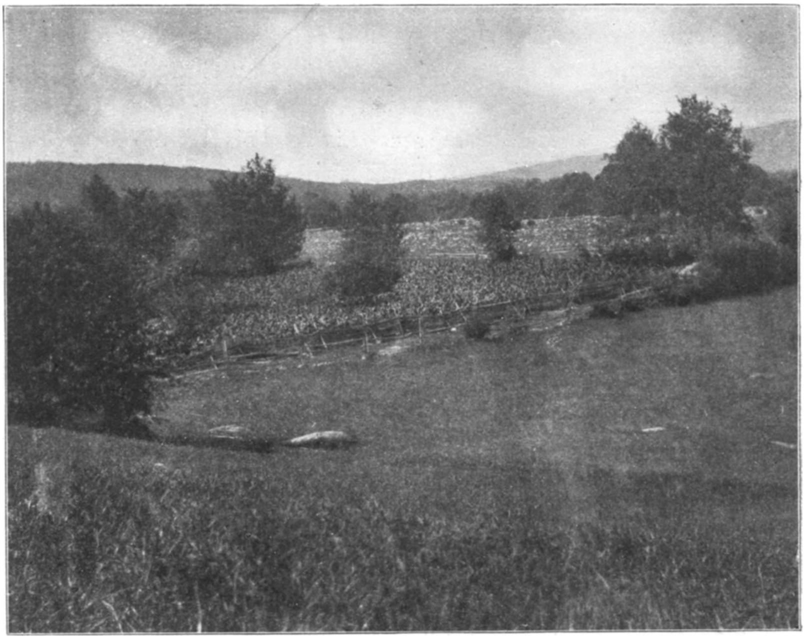

FIG. 4.— Looking southwest across old channel, two miles south of Hartsville, Mass.

strongly developed and has an outer morainic ridge or bank like a parapet or levee running, with occasional breaks, for two miles or more. It runs along the hillside half a mile east of the Konkapot river and about 130 feet above it. Fig. 4 is a view from the hillside looking southwest across this river bed, which is here about 200 feet wide. The meadow and the cornfield are on the floor of the channel, beyond which the stony parapet ridge may be seen rising ten feet or more above the channel floor. This type of lateral moraine, however, is rarely seen, the more common type being the smooth submarginal form.

Fig. 5 shows a well-defined lateral moraine on the southwest flank of East mountain about three miles northeast of Hancock, Mass. The heavy bank of till rises conspicuously to a certain level above which the drift coating over the rock is thin. The fresh gulley recently cut by a rivulet shows the composition of the mass. The end of this tongue was on the right at Brodie pass.

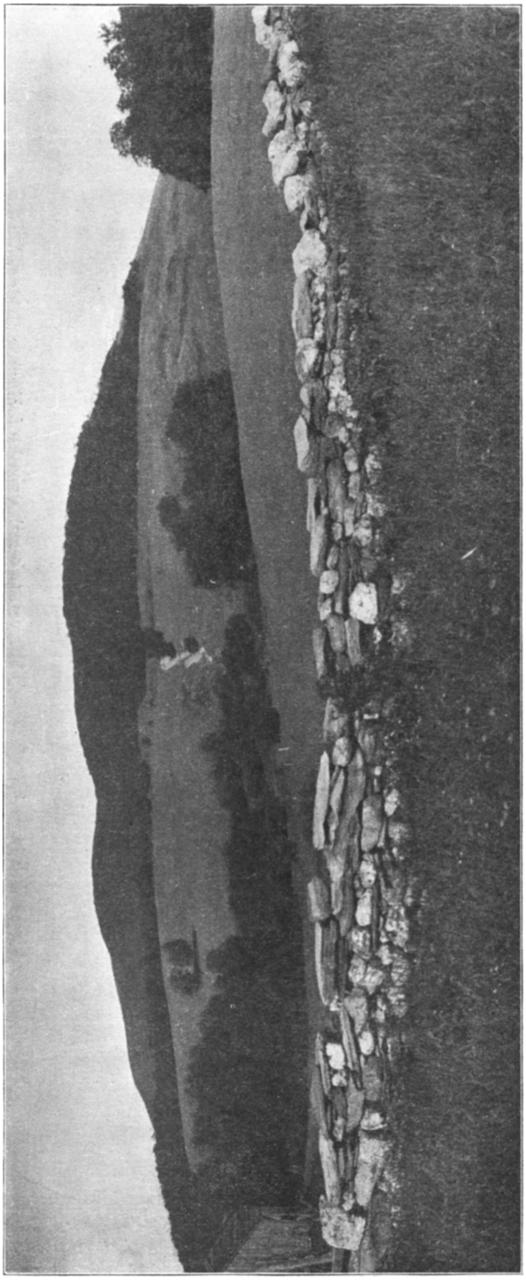

FIG. 5.—Looking northeast, three miles northeast of Hancock, Mass.

Fig. 6 is in the valley of Deerfield river near the mouth of Dunbar brook about two miles below Monroe Bridge. This is a remarkable locality. The mountain wall on the left rises over 1,000 feet from the river, in one

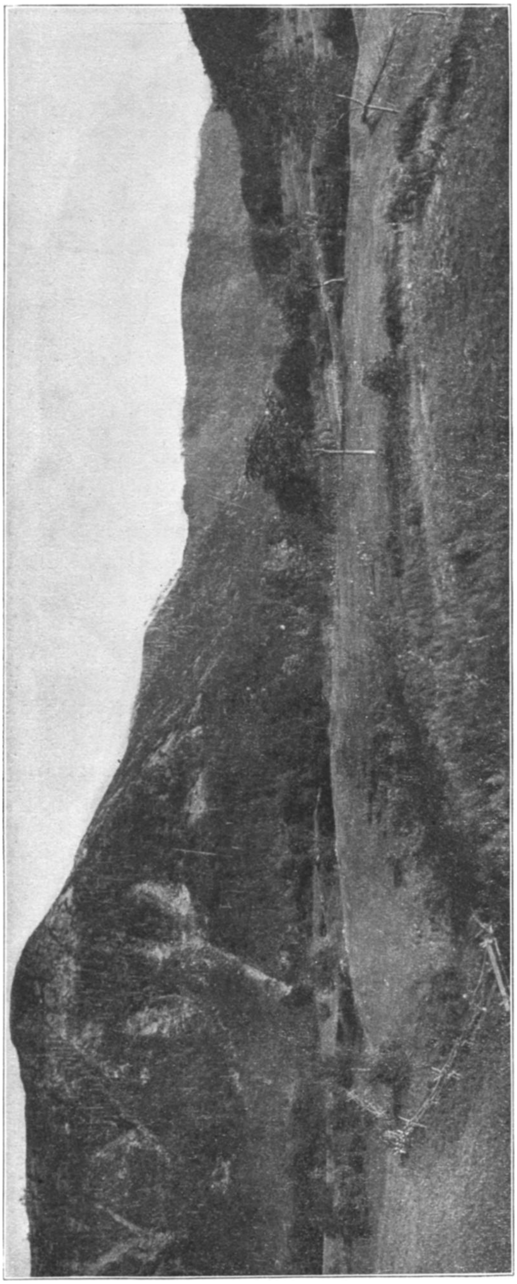

FIG. 6.—Looking south in valley of Deerfield river, two miles south of Monroe Bridge, Mass.

place rising nearly 900 feet in one-sixth of a mile, thus giving a slope of forty-five degrees. Two moraines are seen here in one view. The near foreground in the center is the outer end of an esker which turns to the left and then to the south at sharp angles. This esker seems to come out of the ravine of Dunbar brook, and appears to have belonged to a narrow ice-tongue which emerged from that ravine into the Deerfield valley whence it spread in the shape of an anchor with a short prong up and a longer one down the Deerfield. The hummocky ground under the hill at the right is full of knobs and basins, and is a part of

the terminal deposit of this tongue. On the lower shoulder of the hill at the left and to the right of the tracks of the snow slides there hangs a fragment of gravelly morainic deposit about 300 feet above the river and belonging to this moraine. A little farther down at a lower level there are heavy morainic deposits continuous with it. These and the hanging fragment are better shown in Fig. 7. It may be noticed in Fig. 6 that the forest

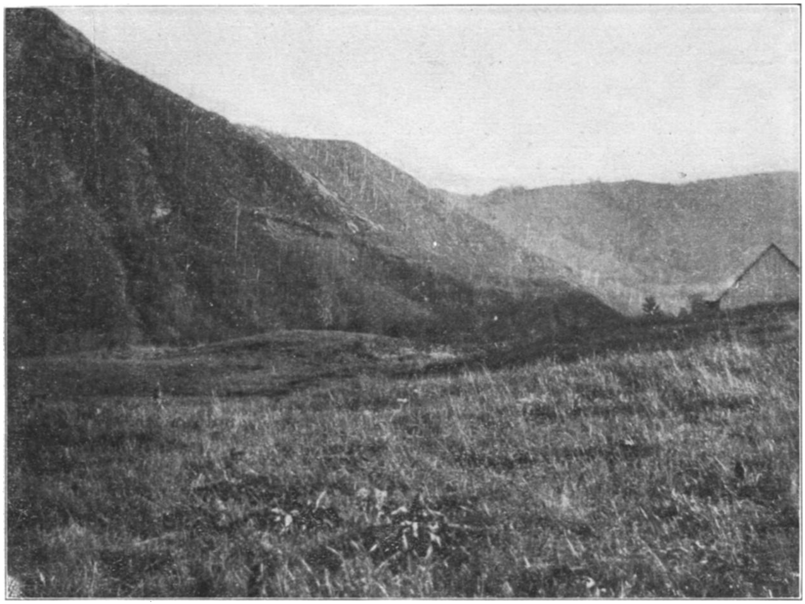

FIG. 7.—Detail of hanging fragment of moraine shown in Fig. 6.

extends up the hillside to a certain line near the top, perhaps 200 feet from the summit, and that the snow slides begin at this same line. Above this line the rock is practically bare, but below it there is a coating of till which supports the forest. The upper limit of the snow slides marks the limit of the ice during the halt next preceding the time of the Dunbar ice-tongue, and the till coating where the several slides occur may be regarded as a thin lateral submarginal moraine. The end of the tongue at this halt was near Zoar.

There are many other good examples of lateral moraines,

especially along the west slope of Hoosac mountain and on the hills north of Williamstown. The latter, however, are very much modified by the strong border drainage that was associated with them. On this account they show a much greater proportion of coarse sediment than usual and also a more varied topography.

(4) *Stoss moraines.*—These are moraines that are banked up on the stoss-side of hills or mountains which stood in sharp re-entrant angles of the ice-front. They have the same general character as the lateral moraines described above, and might perhaps be included with them. Like them they are distinctly submarginal and very smooth in expression and seldom well developed. They differ, however, from the lateral moraines somewhat in the manner of their occurrence and in their associations. Only a few good examples were seen, and none of these appeared to have border drainage associated with them nor any deposits of sand or gravel. The best example of this class was found on the north slope of Miles mountain, a mile and a half southwest of Ashley Falls. The north slope of this mountain is covered with a heavy coating of bowldery till up to about 300 feet above the river, but here the till suddenly grows thin.

All through the Berkshires the normal action of the glacier on the steeper stoss-slopes of mountains was to rub them hard and sweep them clean of all loose materials. Following this rule, the steeper stoss-slopes of the mountains are usually bare or only very thinly coated with drift. The drift sheet of the valleys usually rises somewhat upon their lower flanks, but this cannot be counted as a marginal deposit. However, where a high stoss-slope which would normally be swept bare is found to carry a heavy bank of bowldery till up to a certain height, above which the hill is mostly bare, the explanation seems to be that the bank of till was deposited just under the edge of the ice when the ice-front rested there and was depositing, and hence not sweeping heavily up the slope and over the hill. Stoss-slopes are swept bare most effectively when situated under the ice at some distance back from the edge and when the ice mass is moving freely over the tops of the hills. On Day mountain, which rises south of Dalton, there is a similar deposit.

We have seen in Fig. 4 a good illustration of the work of border drainage. The stream which made this channel was larger than most border streams within the Housatonic quadrangle, for it was the outlet of a temporary lake which filled the Monterey valley and drained a considerable area of land and ice lying to the northwest. None other equal to this was found, but there are good records of border drainage along the base of Peru hill east of Hinsdale; three miles directly south of Tolland; south of Mill River and from New Marlboro south and southwest; along the hill east of Sheffield; north of Salisbury and northeast of Hillsdale, N. Y. West of the quadrangle splendid lines of border drainage run southwest from Brainard, from East Chatham, and from near Spencertown.

In the Taconic quadrangle, so far as investigated, border drainage was found particularly strong where the ice-front rested against the Green mountains between Bennington, Vt., and Williamstown, Mass. It is strong also between North Adams and Cheshire along the flank of Hoosac mountain.

But some of the finest examples of border drainage are those associated with the later outlets of Lake Hoosic. As soon as the retreating ice-front withdrew from the north end of the Rensselaer Grit plateau, Lake Hoosic found lower levels of discharge in that vicinity. At four or five successive halts the outlet river found a new and lower course to the southwest along the front of the ice, and in each position it made a well-defined channel, and built a sandy delta each time where it struck the level of the Hudson estuary.

INTERPOLATION BETWEEN MORAINE FRAGMENTS.

The study of the ice-border in certain localities, where either border drainage or the lateral as well as the terminal moraines were traceable, has furnished the basis of a rule for interpolating re entrant angles around hills and mountains from one terminal deposit to another. One of the best examples showing this relation may be seen in the Housatonic valley south of Pittsfield. The apex of this tongue rested at Lenoxdale, and at this place there is a very conspicuous terminal deposit. A small

amount of bowldery till rises upon the flank of the hill along the east side, but the deposit is mainly a combination of kame and delta. The Housatonic river has found a way around the west side of the deposit. At the north end is a very tumultuous pebbly kame deposit, with pronounced knob-and-basin structure, while to the south the undulations fade away upon a level gravelly surface which terminates in an abrupt bluff at something more than a mile. The bluff has been made more steep by recent erosion. Toward the south the terrace is composed of stratified fine sand, except about fifteen feet at the top, which is coarse gravel. Two or three kames rise as sharp cones forty feet above the delta. One is shaped like a mesa, but narrows into a short but well-developed esker at the north. This tongue projected into Lake Housatonic, and it was in the water of this glacial lake that the delta and kames were made.

The Housatonic valley in this part is bounded on the east by the plateau front and on the west by Lenox mountain. Five miles north of Lenoxdale the plateau front turns to the east and Lenox mountain comes to an abrupt end. The ice-tongue evidently projected between these stolid sentinels. On the east side there appear to be no prominent features marking the ice-border. But on the west side the edge of the ice along the side of the tongue is prettily marked by a small lake and by the channel of its outlet, and in one place by morainic sediments. Two miles and a half north of Lenox and west of the main road there is a slight ridging up of the till into the form of a moraine. To the west this originally extended across the expanded portion of a ravine, coming out of Lenox mountain at the southwest. When the ice stood here it held a small lake in the ravine, and there are some small kames made by a stream which entered this lake from the ice. Eastward and southward, passing three-fourths of a mile east of Lenox, is a small but well defined old river bed which holds its course along the eastward slope nearly down to Laurel lake. Just east of Lenox it branches and takes a lower route a quarter to half a mile farther east and runs about parallel to the same destination. The two branches of the channel represent two positions of the ice-front during this halt.

The Yokun river drains the ravine, and the little lake may be known as Yokun glacial lake. It is near 1,350 feet. above sea-level, while the top of the terrace at Lenoxdale is close to 1,020 feet. The base of the terrace is about 960 feet, and this is taken as the basis of measurement. The distance is about four miles from the central part of the terrace to the nearest part of the Yokun glacial lake. Hence the rate of slope along the side of this ice-tongue was nearly 100 feet per mile.

Several other tongues within the area studied afforded similar evidence, but generally the rate of slope indicated was slightly greater, between 100 and 110 feet in a mile. This rate was used as the basis for interpolating from the ends of tongues up to the re-entrant angles at their sides, and has seemed to give satisfactory results. The rate of slope is a little greater where tongues are very narrow, and a little less where they are broad. The average slope along the side of the Hudson lobe, regardless of the tongues and re-entrants, is something between twenty-five and thirty feet per mile.

In the Olean[1] and Salamanca quadrangles Leverett found the side slopes of tongues which reach down the ravines to the Allegheny river to vary between 100 and 130 feet per mile, or slightly steeper than those here reported for the Berkshire region.

Salisbury found the slope at the ice-front at Baraboo, Wis., to be 320 feet per mile. Other estimates of slope quoted by him are for the surface of the ice at points some distance back from its edge, where the slope is always less than at the front.[2]

THE CONTINUOUS AND SEPARATE INDIVIDUALITY OF THE RECESSIONAL ICE BORDERS.

The remains of the ice-borders in the Berkshires are mostly so faint and so fragmentary, and the fragments are so scattered about in the valleys and on the hillsides, with so little appearance of order or arrangement, that a map showing these features alone is unintelligible; it appears for the most part like a mere

[1] Pocket map in Monograph XLI, *U. S. Geol. Surv.*

[2] "Glacial Geology," *Geol. Surv.*, *New Jersey*, Vol. V, pp. 41–3.

aggregation of spots, without any scheme of orderly arrangement, as shown in Fig. 8. This appearance arises not only from the fragmentary character of the evidences, but is greatly increased by two other causes—by the shortness of the average interval between the successive halting places, and by the extreme sinuosity of the ice-front at every halt. If the successive halting places had been farther apart, say fifteen or twenty miles on the average, instead of three and one-half, the continuity of the successive ice-borders would have been more apparent; for each one would have stood out as a recognizable continuous individual, inspite of the fact that it was represented only by a sinuous line of fragments.

In order to see the true relations in the Berkshires it is necessary to revert briefly to some of the larger elements of the situation. The Hudson valley was occupied by a great glacier lobe, low and sharply pointed at the south, but rising to higher and higher levels to the northeast along its eastern border until it overtopped the highest summits of the Berkshires. It was the ice of this lobe that overspread Berkshire county, and it was its retreating eastern limb or margin which made the recessional moraines. Each time the ice-front halted it fitted itself to the rugged topography with which it happened to be in contact at that time, projecting a series of tongues in the valleys and forming high re-entrant angles on the intervening hills. Thus the border of the Hudson valley lobe was made intensely serrate by the ruggedness of the local topography, and it was this that gave the course of the ice-border so many sinuosities and determined the peculiar distribution of its associated deposits. When the Hudson lobe began a movement of retreat, its border drew back all along the line until it reached the place of the next halt; then it halted all along the line, and whenever it advanced it proceeded in the same manner. There is no reason to believe that different parts of the margin of the lobe had dissynchronous movements, such as would be the case if one part retreated while another remained stationary or while still another advanced. Everything we know tends to the conclusion that the movement at all points was synchronous or in unison along the entire side of the lobe.

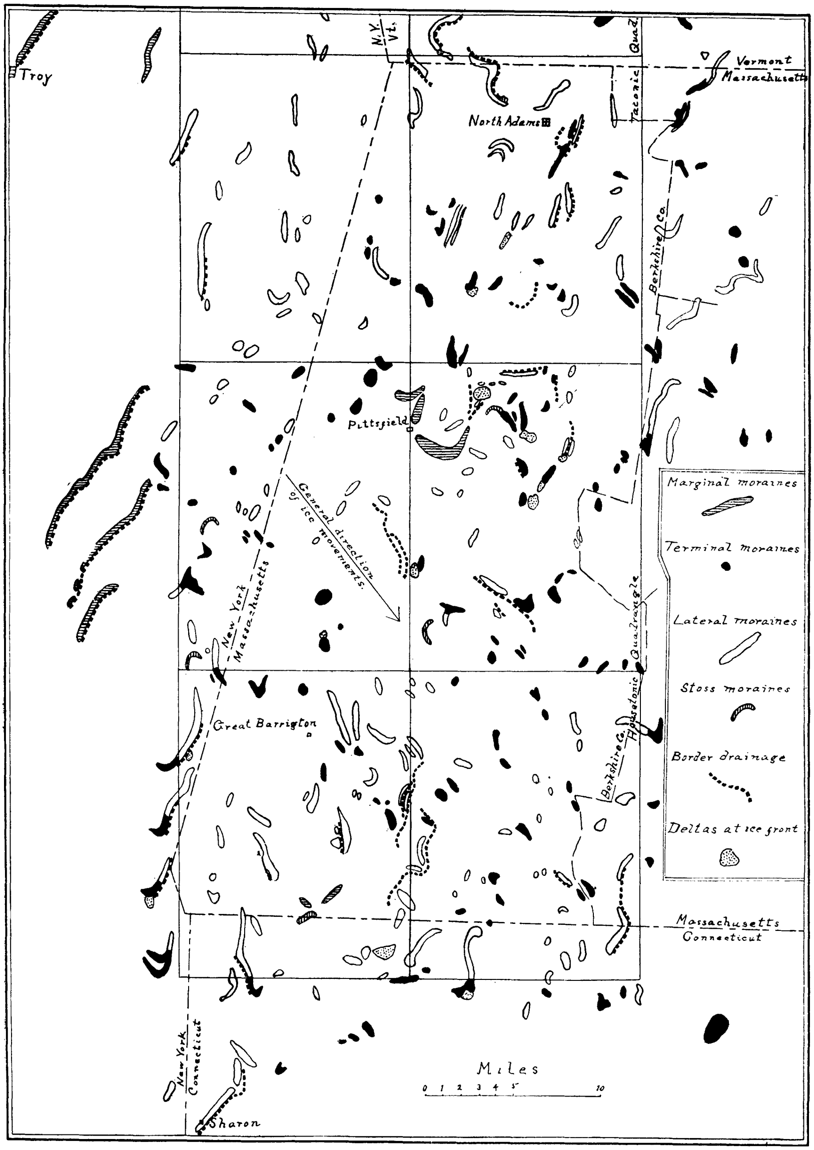

FIG. 8.—This map shows the distribution of morainic and border drainage features without any interpolation. When drawn upon the topographic contour maps, their relations to topography are brought out, and their distribution and arrangement are more intelligible. All moraine fragments which seemed uncertain in their relations to the ice-front are represented on the map as lateral.

These considerations disclose the true relation of the Berkshire ice-tongues to the Hudson lobe. They were absolutely dependent upon that lobe for all their movements, and they reflected its conditions in the most intimate way. They were all parts of the lobe itself and constituted a mere fringe along its border. If Berkshire county had been an even plain, either flat or gently inclined, the border of the lobe would have crossed it in straight lines, and the recessional moraines would have been straight and parallel. There would be no reason, then, to suppose dissynchronous movements at different points on the line. The rugged topography has not altered this relation. It produced a fringe of ice-tongues, but those tongues had no dissynchronous movements among themselves. They all advanced at one time, they all retreated at one time, and they all halted at one time.

The conclusion to be drawn from these considerations is that the ice-border at each halt rested on a line which was distinct and separate from the line of the halt that preceded it; so that if perfectly continuous moraines had been made along the entire margin at each halt, these moraines would now be separate and distinct individuals, extremely sinuous, but still roughly parallel and *without any overlappings*. Local differences of climate may have produced some slight dissynchronism of movements, and glacial erosion may have added a little to the same result, but the effects attributable to these causes appear to be so small as to be well within the ordinary width of the moraines. Sometimes moraines are a mile and one-half to two miles wide, and they are then generally composed of three or four secondary ridges more or less distinct, suggesting waverings or changes in the position of the ice-front during the halt. Border drainage channels often show the same waverings. But whether these very slight waverings were due to general or local causes is not yet clear.

Alpine glaciers, on the other hand, show widely dissynchronous movements.[1] While one advances, another retreats, and

[1] H. A. REID, "Variations of Glaciers," reports in several recent volumes of the JOURNAL OF GEOLOGY.

still others may be at a standstill. The cause of this lack of unison in movements is found in the fact that Alpine glaciers are fed from separate snow-fields. Their gathering grounds are on the high flanks of mountain peaks or ranges, and each glacier has its own basin, or cirque, in which its snow accumulates. The varying conditions of snowfall in individual storms, and in different months and years and periods of years, furnish abundant reason for their individual peculiarities and dissynchronous movements.

But although their forms often bore some resemblance to Alpine glaciers, the ice-tongues of the Berkshires were not of the Alpine type. They were not fed by independent snow-fields, but were all simple offshoots from one ice-mass—the Hudson valley lobe. They were all fed from one source, and whatever affected that source affected them all alike. There appears to be ample reason, therefore, for believing that the recessional halts in the Berkshires were separate individuals without overlappings.

But while these conclusions may be safely applied to the Berkshires, and would probably be applicable in other regions where the relations were equally simple, it is not intended to imply that they would be a safe guide everywhere. There is much reason to believe that the great lobes, like the Hudson valley and Lake Ontario lobes, had movements somewhat dissynchronous, so that as between two such lobes the principle of correlation here suggested might not apply.

In the Berkshires, however, this seems to be the one thing needed. It seems to furnish the only possible basis of correlation by which the fragments of the recessional moraines can be connected together and the ice-borders reconstructed as they actually existed. With one or two ice-borders clearly made out in continuous form for a sufficient distance to show their general trend, with branching and interlacing series of terminal deposits made by ice-tongues at consecutive halts in the main valleys, and with a moderate amount of interpolation between adjacent fragments applied according to rule as given above, it becomes possible to reconstruct in continuous form all of the recessional ice-borders

of Berkshire county. Of course, the certainty of correlation and reconstruction varies in different localities according as it is necessary to use more or less interpolation. For example, across Mount Washington the course of the ice-borders is almost wholly interpolated. The few fragments of moraine found on the mountain are so far from those in the surrounding valleys that their connections must remain uncertain. These lines, however, are not drawn by mere guess, but as closely by rule as possible, and are projected from points of observation in the valleys near by. The terminal deposits in the valleys on both sides of the mountain are mostly well developed and form an excellent basis for correlation. About the same amount of interpolation was used on Greylock mountain. The lines across Hoosac mountain are somewhat less certain, but they are based on excellent data in the valleys on both sides. The Green mountains, the northern part of the Taconic range, and the Rensselaer Grit plateau have not yet been sufficiently studied for mapping. In the rest of the area interpolation is used in less degree and is generally simple, and reconstruction of the ice-fronts is correspondingly easier.

THE BECKET AND LENOXDALE MORAINES.

Where ice-borders are represented by moraine fragments scattered in such disorderly fashion, it is fortunate to find two or three sections of some length in which the evidence for continuity is complete. Such sections establish the general trend of the ice-border and form excellent bases for the correlation of other less clearly connected fragments of near-by earlier and later borders. The second moraine, as shown on Figs. 9 and 10, is substantially continuous from Tolland to Colebrook, only a very little interpolation being required to complete the line between these places. There are a number of other sections of similar length, the continuity of which is quite clear. But besides these there are two longer sections, which in their combined length reach entirely across the Housatonic quadrangle from southwest to northeast. These are the Becket and Lenoxdale moraines, parts of the sixth and eighth, as shown in Figs. 9 and 10.

Beginning at a point about three miles northeast of Tyringham, the Becket moraine is readily recognizable as a continuous line for a distance of twenty-five miles, or to a point two or three miles northeast of Plainfield. The continuity of this line is evident simply from the closeness of the moraine fragments of which it is made up, and from its distinct separateness and lack of confusion with the fragments of other earlier and later moraines. The line of fragments stands out quite clearly as a unit in Fig. 8, where no interpolation is employed.

The other section is part of the Lenoxdale moraine. This one has much larger tongues and re-entrants, and might at first seem an unlikely case for clearly established continuity. But its relation to Lake Housatonic fixes the contemporaneity of two of its most widely separated tongues. As we have seen above, the great kame-and-delta terrace at Lenoxdale was built in a lake. If there had been no obstruction in the narrow valley of the Housatonic river below Glendale, the water would have passed out by that course as it does now, and there would have been no lake. There is another great kame-moraine deposit, with some delta gravel, at Glendale, showing conclusively that the ice-border stood there also in a lake. More than this, at the Konkapot col, three miles east of Great Barrington, there is the head of a well-marked eroded river bed which was the outlet of the lake in question, and this outlet is at an altitude of about 1,000 feet above the sea level—about the same as the top of the fine sand in the Lenoxdale delta. There is also a beautifully cuspate lake delta at East Lee at the same level, and the highest part of the Glendale deposit stands at about the same. It seems plain, therefore, that the ice-tongues at Lenoxdale and Glendale stood in their places at the same time, and that there was between these tongues a deep, wide re-entrant around Lenox mountain. From Glendale to Hillsdale, N. Y., the closeness of the moraine fragments and their distinct separateness from the fragments of earlier and later lines leave no doubt of the continuity of the Lenoxdale ice-front. This section also is about twenty-five miles long.

The Becket and Lenoxdale moraines are roughly parallel,

and between their ends, which lap past each other, there are fragments of another moraine at East Lee and Washington. Supposing the successive moraines to be distinct individuals, as stated above, the correlation of fragments of other moraines with either of these continuous sections has the same significance as though they were correlated with the same point in a single series. These relations furnish the basis for reconstructing the several recessional ice-borders.

BRANCHING AND INTERLACING SERIES OF TERMINAL MORAINES.

With the aid of two or three ice-borders made out clearly as continuous units for distances of twenty or twenty-five miles, like those just mentioned above, it becomes possible to reconstruct other near-by ice-borders whose continuity is not so clear when taken by themselves. This can be accomplished by the correlation of branching and interlacing series of terminal moraines in their relation to the identified continuous lines.

The most favorable condition for the formation of a complete series of moraines that shall make a perfect record of the successive recessional halts occurs where a deep, narrow valley drains directly away from the receding ice-front and keeps this relation during many successive halts. This is the relation of the Farmington valley. From its head near East Lee it cuts through the plateau a few miles to the east, then turns to the south, and passes out of the county and out of the Housatonic quadrangle near the southeast corner. The earliest ice-border which rested within the area of the Housatonic quadrangle crossed the extreme southeast corner a mile west of West Hartland. It was a re-entrant angle of the ice-front and is a faintly developed feature, but it is here designated as No. 1 of the series. Counting up the moraines in the Farmington valley, beginning with the one north of Riverton as No. 2, we find that the deposit at West Becket on the line of the Becket moraine is the sixth, the one east of East Lee the seventh, the one at Lenoxdale the eighth, and the one at Pittsfield the ninth. The moraines of this series are distinct, well-formed individuals, and would be readily recognized by any experienced observer. A careful

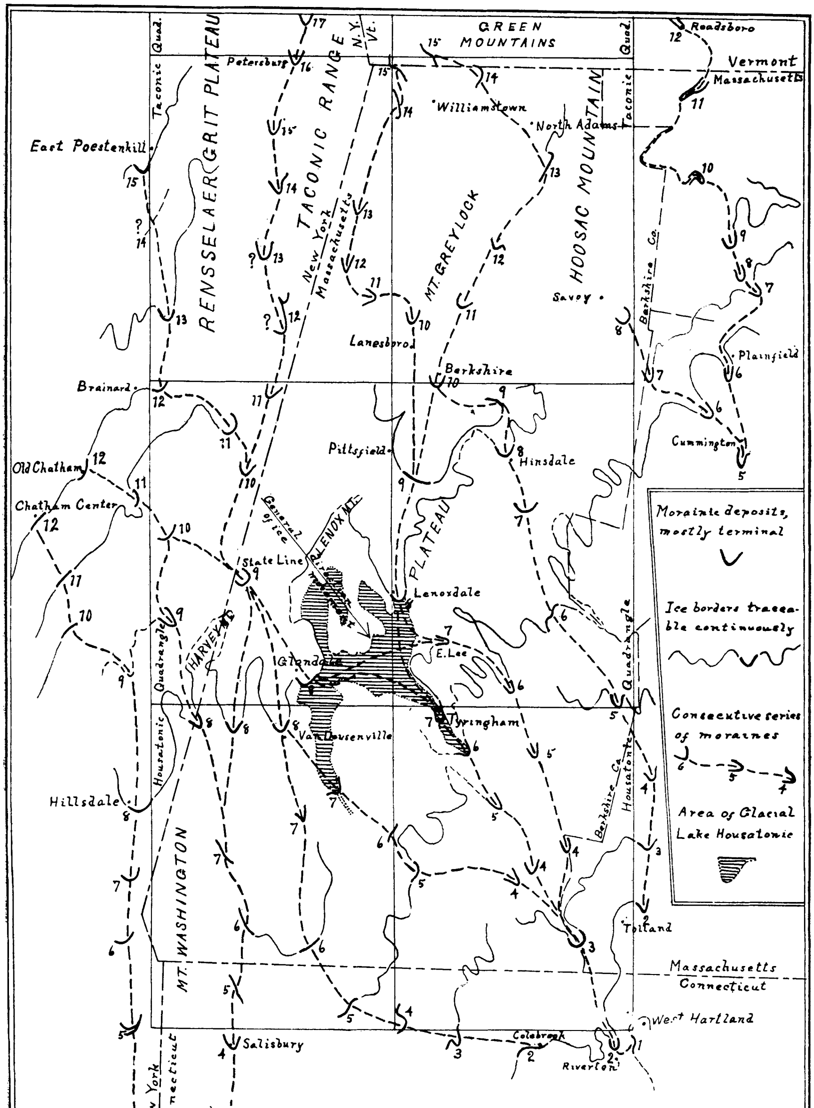

FIG. 9.—This map shows the scheme by which the moraine series in one valley is correlated with that in another parallel or branching valley. This scheme, supplemented by the rule of interpolation between adjacent ice-tongues of the same halt, forms the theoretical basis for the reconstruction of the several recessional ice-fronts, as shown in the next map. Some of the best lines, which are traceable with substantial continuity, are shown upon this map. Nos. 2, 6, 8, and 12 form the principal foundation for the application of the scheme. The area of Lake Housatonic is represented in order to show the contemporaneity of the Lenoxdale and Glendale ice-tongues.

study of the valleys in which these tongues lie shows further that there are no other recognizable terminal deposits in them. The deposits at Cold Spring and at North Otis show some complexity, because they are spread up and down the valley a little more than usual, in each case showing earlier and later phases of deposition which are one to two miles apart. But a little experience enables one to recognize the fact that deposits like these are due to the waverings of one halt.

South of East Lee the deep Tyringham valley comes in from the southeast. Over the col at its head it is continuous with the valley of Clam river, which joins the Farmington at New Boston. Counting the moraines up the valley again from Riverton by way of Clam river, we find the deposit at Tyringham to be the seventh or the same as that at East Lee, with the eighth at Lenoxdale as before. Here we have a branching series in which the first two are common, but north of the second one two parallel branches run up to the seventh. The branches diverge so little that they are not over four miles apart at any point. In a simple branching series like this it can hardly be doubted that the two deposits which stand as No. 4 in each series belong together as parts of one halt line, and the two deposits marked No. 5 as parts of a different later line, No. 6 as parts of still another line, and No. 7 as parts of still another. At Lenoxdale the two branches reunite as one.

From New Boston another series may be followed more to the west past Montville, New Marlboro, Hartsville, and the Konkapot col to Van Deusenville, where again is found the Lenoxdale moraine, which is the eighth of the series. This series, however, is not quite so good as either of the others, for it does not lie in a single trough or in a pair of head-joined valleys, like the other two, but crosses the hills from the Farmington valley to the Housatonic.

The moraine north of Riverton is easily recognized as part of a line which runs westward to Colebrook. Beginning at this place as No. 2, another series may be followed northwest to Van Deusenville as before, but by a different route through Norfolk, West Norfolk, East Canaan, Ashley Falls, and the hillside south-

east of Great Barrington. Part of this series is somewhat less distinct than the preceding, but still is clear enough, and here we have four branching series of six terminating in No. 8, which is well determined as a continuous line.

In order to get the best possible basis for carrying the ice-borders by interpolation across Mount Washington, it was necessary to extend investigations some distance to the south beyond the limits of the quadrangle. The Housatonic valley passes close along the base of the mountain on the east, and the Copake valley along its west side in New York. In the latter valley there is a fine series of terminal deposits, which may be counted from the north, beginning with the Lenoxdale moraine at Hillsdale as No. 8. The seventh, then, is at Copake Furnace, the sixth at Boston Corners, the fifth about two miles north of Millerton, the fourth at Indian Lake, and the third at Sharon, Conn. This is as far as this series has been made out, but it is as strong and distinct as the series in the Farmington valley. At Sharon, and for three miles northeast, there is a well-defined moraine running along the edge of a bench near the northwest base of a mountain ridge extending in the same direction. The ridge is east of the moraine, and between the two there is a well-defined abandoned river bed averaging about an eighth of a mile wide. Beardsley pond lies in the course of this channel. The east side of the moraine facing the river bed is gravelly and sandy most of the way. At a point about three miles northeast of Sharon the river bed seems to have an abrupt beginning on the brow of a low ridge, overlooking Beaslick pond to the north 100 feet lower. There is no sign of such a river bed in that direction. The moraine turns to the north a mile south of the pond and changes its character, becoming a heavy till ridge of smooth form with very little sand or gravel. East of this ridge, and separated from it by the sharp depression in which Beaslick brook flows, is another heavy, smooth till ridge of precisely similar character. These ridges are about eighty feet above the adjacent low ground, but may not be wholly composed of drift. North of the pond these ridges are nearly parallel, but at the pond they diverge and turn away in opposite directions. The

eastern one turns off to the east and is soon lost on the hill above Salmon creek, while the western one follows the bench to Sharon as described.

The relations here are highly significant and afford a strong basis of correlation around the two sides of Mount Washington; for evidently the large river, which seems to start so abruptly where the two moraines diverge, came from the northwest along a crease or depression in the ice. The ice-sheet advancing down the Copake valley on the west side of Mount Washington pressed eastward over the relatively low ground north of Sharon and west of Lakeville, and met the ice coming down the Housatonic valley on the east side of the mountain. A moraine along the southeast flank of Mount Washington north of Lakeville appears to belong to this same halt and indicates that a large portion, probably nearly one-half of the mountain, remained at that time uncovered as a nunatak. All of the drainage of the nunatak and of as much of the adjacent ice-field as sloped toward it found its way of escape along the crease between the two lobes and thence down the old river bed past Sharon. Since the ice has disappeared, the bed of the river in the ice-crease has gone, and no trace of it remains. This is why we find the river bed appearing suddenly where it emerged from the crease.

The significant fact which this relation establishes is this, viz., that the two moraines which diverge from the crease belong to the ice-border of one and the same halt. This enables us to say that if the Sharon moraine is No. 3, in a series numbered down from Hillsdale, then the east moraine at the crease is the same number counting down the Housatonic from Van Deusenville. Part of the latter series is not so strong as that between Sharon and Hillsdale, for the moraines in the Housatonic valley are mostly faint and weak. Still, well-developed small fragments may be seen at Salisbury for No. 4, west of Chapinville for No. 5, near Ashley Falls for No. 6, and on the mountain flank southeast of Great Barrington for No. 7. It would be hard to think of a more beautiful correlation between two series than that which is furnished by the peculiar relations of the Sharon glacial river.

There is another series of terminal deposits east of the Farmington valley almost as fine as those of the Farmington and Copake valleys. From the moraine north of Riverton the lateral moraine and border drainage is quite clear most of the way along the valley side north to Tolland, where the ice-border turned to the east. Starting with the deposits near Tolland as No. 2, there is a well-defined series running to the north past North Blandford, Becket, Washington, and Hinsdale to the moraine north of Dalton, which is the ninth in the series and the same as the Pittsfield moraine. The deposits at Tolland are rather faint, but all the other members of this series are well developed.

Passing out of Berkshire county into New York we may extend the series from the Lenoxdale moraine to the northwest corner of the Housatonic quadrangle. This may be done by following the series of terminal deposits from Van Deusenville as No. 8 past State Line, and thence north and west past Lebanon Center to moraine No. 12 east of Brainard. From here the series may be extended north to No. 15 at East Poestenkill. Outside of the quadrangle a series may be followed from No. 8 at Hillsdale to No. 12 at Chatham Center. Or, another good line runs from No. 8 south of Green River past Austerlitz to No. 12 at Old Chatham.

From the Pittsfield-Dalton moraine (No. 9) the series may be extended northward by two routes so as to surround Mount Greylock. One line runs through Berkshire, Cheshire, Adams, and North Adams to two lateral moraines northeast and north of Williamstown, the last one being No. 15 in the series. The first four are terminal deposits. Berkshire village is just north of the col between the Housatonic and Hoosic valleys, and the terminal deposits there and all those along the Hoosic river north of there, were laid down in the water of Lake Hoosic. From North Adams down, the lake was so deep that the terminal deposits are unrecognizable, and the positions of the tongues have been determined mainly by lateral deposits and border drainage features on the flank of the Green mountain range at and above the level of the lake. At Williamstown the lake was 500 feet deep. The conditions along the flank of the Green

mountains favored the making of a strong record of glacial border deposits at every halt. The drainage features especially are very pronounced, and their value for determining the recessional series is almost equal to the terminal deposits of deep valleys with free drainage.

The other series running north from Pittsfield passes by way of Lanesboro and the Hancock valley to two lateral moraines on the flank of the Taconic range west and northwest of Williamstown, the last one being No. 15 as in the other series. Some of the individual deposits of this series are not so strong as those of the series through North Adams.

One of the best series found is that which extends northward in the Lebanon and Berlin valleys along the west side of the Taconic range, but the study of these valleys is not yet completed. Beginning with the tongue at State Line as No. 9, the series runs directly north past Lebanon Springs, Stephentown, and Berlin to No. 17 near North Petersburg, the last four being formed in a deep lake. Four more well-developed moraines lie west of Hoosick Falls. No. 20 passes Johnsonville and enters the city of Troy from the northeast, and No. 21 crosses the Hoosic river three or four miles below Johnsonville, but it is not known whether or not this last one touches the area of the Taconic quadrangle.

Going back now to the country bordering the east side of Berkshire county, we find the Becket moraine (No. 6) extending northeast to Plainfield. The splendid terminal moraine a few miles to the south, near Cummington, seems to belong to No. 5. From this point two series may be traced—one to the northwest up the Westfield river to Savoy, and the other directly north past Plainfield and down the east branch of the Chickley river to the Deerfield at Zoar (No. 10). On account of its depth and narrowness, the deposits in the Deerfield valley are unusually strong and clear, and the series quite easily made out. From Zoar the series may be followed past Monroe Bridge and Readsboro, whence one branch goes northwest past Hartwellville to Woodford on the top of the Green mountain range, while another longer series follows up the Deerfield past Davis Bridge, Sears-

burg, and Somerset to a point about three miles northeast of the northeast corner of the Taconic quadrangle, where No. 16 is found, about four miles south of Grout's mill.

Among these branching and interlacing series of terminal deposits there are several courses by which a complete series may be followed continuously across the county and across the two quadrangles from southeast to northwest. The Farmington-Housatonic-Hoosic series covers the whole interval, and shows that between the southeast and northwest corners of the county the ice-front halted fourteen times, while in crossing the two quadrangles it halted twenty or twenty-one times, the uncertainty depending on the unfinished work at the northwest corner of the Taconic quadrangle.

Along the west side of the two quadrangles on the less rugged slope to the Hudson the recessional moraines can readily be traced as continuous individuals. They run here in lines more nearly straight, the border drainage was strong, and the series as a whole can be made out with a completeness not possible within the limits of Berkshire county. However, so far as the several interlacing series of fragments in the mountain valleys are complete, they may be regarded as safe counters for the enumeration of the recessional series, and if, as assumed above, the several ice-borders of the recession are separate and distinct individuals without overlappings, then the series may be regarded as complete, provided there have been no errors or omissions in observation. In order that there might be the least possible chance of such errors or omissions, the counts have been confined as far as possible to the valley deposits; for in Berkshire county the morainic deposits are concentrated in the valleys and are nearly always more strongly developed there than elsewhere. A series of terminal deposits like any of the stronger ones mentioned above is in fact a series of accentuated points in the recessional moraines. When series do not follow valleys, but cross hills and mountain ridges, they are not by themselves so reliable. Such in part are the two lines from Colebrook and New Boston to Van Deusenville. But where they occur as supplementary lines between clearly defined valley series they may have considerable corroberative value.

In the interlacing series shown in Fig. 9 a considerable number of the morainic deposits and other ice-border features have not been used, as may be seen by comparison with Fig. 8. When these are all studied in their relation to the several members of the interlacing series, it is found that, with two or three unimportant exceptions, they all fall into line in one or another of the several halting places of the ice-front. Beginning at the southwest with any particular member of the Copake valley series, as for instance No. 6, and going northeast across the interlacing series and noting each deposit numbered 6, the course thus marked out will represent roughly one halt of the ice-front. Then by carefully studying the topography between tongue deposits in adjacent valley series, and allowing for its influence upon the motion of the ice, and making use of all intervening ice-border phenomena as shown in Fig. 8, a fairly accurate restoration of the ice-front at that halt can be made. In doing this the rule outlined above for interpolating around re-entrant angles on mountains or other features with high relief should be followed faithfully. That is to say, in order to restore the ice-front across a mountain ridge between the terminal deposits of two ice-tongues, the tongues having average dimensions for the Berkshire region, allowance should be made for a slope of 100 to 110 feet per mile along the side of the tongue from its point up to the re-entrant angles on its sides.

These are the methods by which the remarkably sinuous ice-borders of Berkshire county have been restored, as shown in Fig. 10. The mean course of any one of them represents the general course of the border of the Hudson valley lobe at that halt. These mean lines are bent from a direct course only by the larger features of topography, such as Mount Washington and the higher ranges to the north. In each one of the sinuous lines represented every point projecting away from the ice-field (generally toward the southeast) is an ice-tongue of more or less pronounced development, and every point projecting back toward the ice-field is a re-entrant angle.

In constructing these lines I have made them continuous where they represent ice-border features actually observed, and

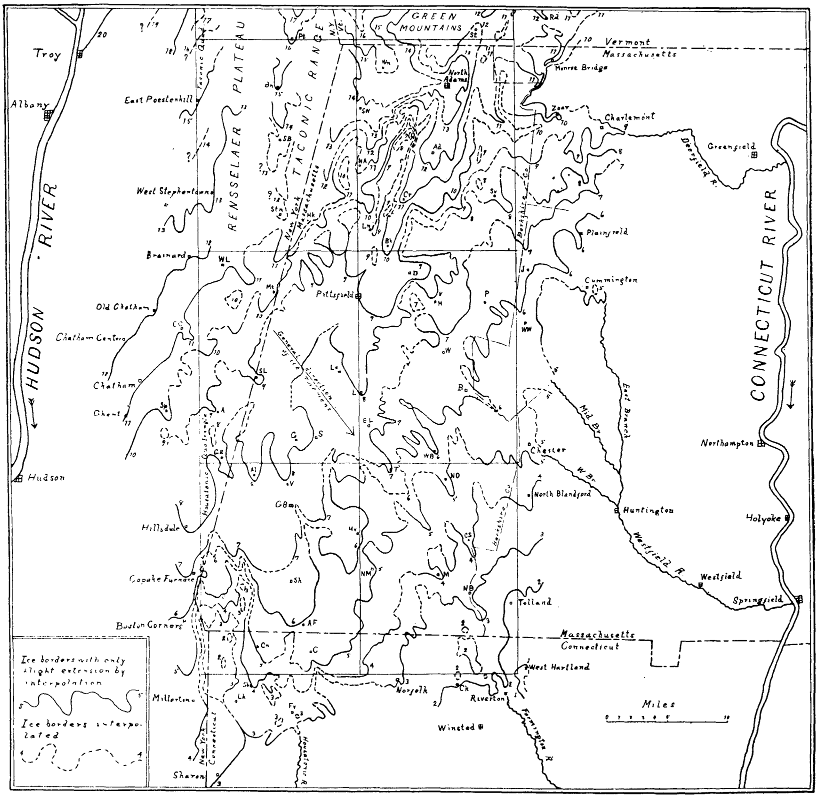

FIG. 10.—This map shows the final results of a reconstruction of the recessional ice-borders by the method set forth in this paper. Parts of the Hudson and Connecticut rivers are included in order to show the general relations of the ice-borders to these two great valleys.

In Connecticut, C = Canaan, Ck = Colebrook, Cn = Chapinville, Fv = Falls Village, Lk = Lakeville, and Sb = Salisbury.

In New York, A = Austerlitz, Bn = Berlin, EC = East Chatham, GR = Green River, Mt = Mt. Lebanon, Pt = Petersburg, SB = South Berlin, Sp = Spencertown, Stn = Stephentown, and WL = West Lebanon.

In Vermont, Rd = Readsboro and St = Stamford.

In Massachusetts, Ad = Adams, AF = Ashley Falls, Al = Alford, B = Becket, Bk = Berkshire, Cr = Cheshire, CS = Cold Spring, D = Dalton, EL = East Lee, G = Glendale, GB = Great Barrington, H = Hinsdale, Hk = Hancock, Hv = Hartsville, J = Jordansville, L = Lenoxdale, Ln = Lanesboro, Lx = Lenox, M = Montville, NA = New Ashford, NB = New Boston, NM = New Marlboro, NO = North Otis, P = Peru, S = Stockbridge, Sh = Sheffield, SL = State Line, Sv = Savoy, SW = South Williamstown, T = Tyringham, V = Van Deusenville, W = Washington, WB = West Beket, Wn = Williamstown, and WW = West Worthington.

I have extended them beyond these features by interpolation for a short distance, which may be defined as interpolation to the first degree. By this I mean that degree or amount of interpolation which any cautious and experienced observer would make without hesitation. Geologists who study the indurated rocks, especially in a drift-covered region, are continually driven to interpolate between outcrops. Where the distance is not great and the relations appear to be simple, such interpolation is regarded as a matter of no great difficulty, seldom involving serious risk of error, and requiring no very critical weighing of the phenomena for its application. It is like interpolating the course of a brook through a wood lot or a thicket when the places of its entrance and exit are known and the general relations are seen to be simple. Of course, many small errors will inevitably arise from such interpolation, but they seldom affect the larger elements of the problem in hand. The first degree of interpolation goes but a little way beyond what we can actually see. Where the restoration of the ice-borders in Fig. 10 has been accomplished by the use of interpolation which involves more uncertainty than the first degree, as here defined, I have drawn them as broken lines. Of course, the limit of the first degree of interpolation is an arbitrary one, but I have endeav ored to keep on the safe side. The higher mountain areas, like Mount Washington, showed very few recognizable ice-border features and the course of the ice-borders across these areas is drawn almost wholly by interpolation. In general, therefore, the margin of error is much larger here than in the lower areas. Nevertheless, an effort was made to minimize such errors by carrying the studies over all the contiguous low ground, even where some of this extended outside of the quadrangles.

CONCLUSION.

If these studies have been guided by right methods and the interpretations made on a foundation of correct principles, we seem justified in concluding that the ice-border which retreated to the northwest across Berkshire county was the eastern edge or limb of the Hudson valley lobe; that the positions occupied

by the ice-border at its successive recessional halts were distinct individuals without overlappings; that by the faintness of the moraines and other border phenomena, the halts may be judged to have been of relatively short duration, although when we consider the number of halts which occurred within the interval of fifty miles it can hardly be said that the retreat of the ice-front was rapid, or that it was a sudden dissolution with great floods, as pictured by Dana[1] and others.

That this ice was Hudson ice and came over the Berkshires from the central axis of the Hudson valley seems to be indicated further by the fact that within the area of the two quadrangles studied no stones or bowlders were found which might be suspected of coming from Canada or from the Adirondacks. It seems that the Adirondack ice never crossed to the east side of the Hudson-Champlain trough, and further that any bowlders which may have started from Canada down the axis of this trough found it impossible to keep the line of that axis far enough to reach the Berkshires. The continual divergence of the ice to one side or the other of the axis appears to have side-tracked all the Canadians before they got so far south. The same fact seems to account in part for the very local derivation of nearly all the drift in the Berkshires. Exceedingly little came from points as far north as Whitehall, N. Y. The great spreading ice-stream which moved down the Champlain-Hudson trough domineered those valleys through every stage of the glacial invasion and was never diverted from its course.

In his recent admirable report on the glacial geology of New Jersey, Salisbury observes that "the edge of the ice might have halted in one place and not at another at the same time. Moraines of recession are therefore sometimes not traceable for long distances."[2]

[1] J. D. DANA, "The Flood of the Connecticut River Valley from the Melting of the Quaternary Glacier," *Am. Jour. Sci.*, III, Vol. XXIII (1882), pp. 87–97, 179–202, 360–73; Vol. XXIV, pp. 98–104. C. H. HITCHCOCK, "The Glacial Floods of the Connecticut River Valley," *A. A. A. S., Proc.*, Vol. XIII (1883). WARREN UPHAM, "A Review of the Quaternary Era, with Special Reference to the Deposits of Flooded Rivers," *Am. Jour. Sci.*, III, Vol. XLI (1891).

[2] "Glacial Geology," *Geology of New Jersey*, Vol. V, p. 89.

The entire glaciated area of New Jersey falls within the domain of the Hudson lobe, and its relation to that lobe is precisely the same as that of Berkshire county, Mass., except that the former lies on the west limb of the lobe and near the extreme limit of glaciation. If the principles used for Berkshire county are valid, they ought to be equally valid for the west slope of the Hudson valley, including northern New Jersey. We have seen above that a discontinuous character in the recessional moraines is not necessarily due to dissynchronous oscillations of the ice-front, and that, at least in the Berkshires, there are ways in which the continuity of the successive ice-fronts can be demonstrated, despite the extremely fragmentary character of the morainic deposits.

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FORT WAYNE, IND.,
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